Global climate change: the potential effects on health

Anthony J McMichael, Andrew Haines

Excess carbon dioxide, methane, and other gases which trap heat are accumulating in the troposphere, the earth's lower atmosphere, because of the scale and type of human economic activity. Climate scientists predict that the resultant increase in the troposphere's "radiative forcing" will warm the earth's surface.[1-3] Indeed, in its recent second assessment report, the Intergovernmental Panel on Climate Change—a multidisciplinary scientific body established by the United Nations in 1988 to advise governments—concluded that on balance an anthropogenic influence upon the global climate was now "discernible." [1]

The intergovernmental panel forecasts an increase in the average world temperature of 1.0-3.5°C over the coming century.[1] This forecast is necessarily uncertain because the sensitivity of climate to atmospheric change is imperfectly understood and because future trends in gaseous emissions and modulating processes (for example, the cooling effects of industrial aerosol emissions) cannot be foreseen accurately. Nevertheless, the expected rate of climate change over the coming century would be far greater than any natural change in world climate since the advent of agriculture 10 000 years ago.

Anthropogenic climate change signifies that for the first time the aggregate global impact of humankind exceeds the physical and ecological limits of the biosphere.[4] The potential consequences of this and other global changes (including stratospheric ozone depletion, loss of biodiversity, worldwide land degradation, and depletion of aquifers) are wide ranging. We can expect that climate change will affect the health and wellbeing of human populations in diverse ways. This greatly extends the temporo-spatial scale of environmental health beyond our usual concern with localised and immediate exposures to toxic or infectious agents.[4] A major research task, therefore, is the application of current knowledge to forecasting probable health effects. The primary objective is to provide indicative forecasts of an important consequence that will assist pre-emptive policy making.[5]

Summary points

- Most climatologists believe that global climate change is now occurring as a result of emission of greenhouse gases, especially from fossil fuel combustion. Its expected rate over the coming century will far exceed that of any other climatic change in the 10 000 years since agriculture and human settlement began
- Changes in climate conditions and, possibly, weather variability would affect human health through several processes, many mediated by disturbances of ecological systems
- Changes in the environment to which human biology and culture are adapted or disturbances of ecosystems that set the conditions for health would generally have adverse effects on health
- More readily foreseen effects (resulting from thermal stresses and changed patterns of air pollution) will probably have less impact than will those resulting from complex changes in ecological infrastructure (altered patterns of infectious disease, agricultural production, coastal ecology, etc)
- The types and circumstances of exposure would vary geographically. Populations would vary in their vulnerability because of differences in location, social and technical resources, and concurrent health status

Evaluating scientific reports on climate change

Climate change is a new and rapidly developing topic of scientific inquiry and health risk assessment. We were involved in the detailed review of published studies needed for the chapter on health impact in the second assessment report of the Intergovernmental Panel on Climate Change.[10] Preparation of the report was subject to wide ranging international peer review with contributions, corrections, and criticisms from over 60 scientists worldwide. That text was then expanded to form a book of 10 chapters.[7] This entailed a further intensive review process which included scientists from various United Nations agencies. In preparing this article immediately after those two reviews we have updated information in light of other recent publications.

Assessing potential health impact: issues of context

Forecasting the potential impact of climate change on health calls for the development of risk assessment methods based on scenarios.[5] Details are discussed in

See editorial by Read and Stott

Department of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, London WC1E 7HT

Anthony J McMichael, *professor of epidemiology*

Joint Department of Primary Care and Population Sciences, Royal Free Hospital School of Medicine and University College London Medical School, London NW3 2PF

Andrew Haines, *professor of primary health care*

Correspondence to: Professor McMichael t.mcmichael@LSHTM.ac.uk

BMJ 1997;315:805–9

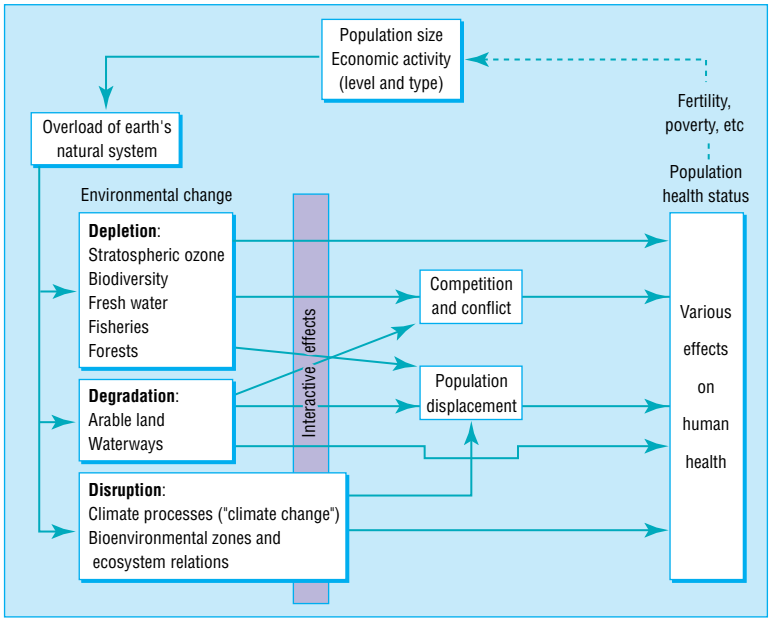

Fig 1 Global environmental change—causes and consequences. Climate change is shown as part of a larger complex of changes

the paper to follow (Oct 3),[6] but it is necessary to note three important issues of context which make this a challenging task. Firstly, the assessment of health risks based on scenarios must accommodate much unavoidable uncertainty, both in the scenarios themselves and in our knowledge of the response of the various linked systems in the causal chain.[5 7] Secondly, many of the health effects would occur as a result of disturbances in complex, non-linear ecological systems which are difficult to model. In addition, the impact of climatic change will depend on interactive effects with coexistent global change processes (see fig 1). Thirdly, the vulnerability of populations is determined by a wide variety of factors (box).

Table 1
Mediating processes and direct and indirect potential effects on health of changes in temperature and weather

Mediating process	Health outcome
Direct effects	
Exposure to thermal extremes	Changed rates of illness and death related to heat and cold
Changed frequency or intensity of other extreme weather events	Deaths, injuries, psychological disorders; damage to public health infrastructure
Indirect effects	
Disturbances of ecological systems:	
Effect on range and activity of vectors and infective parasites	Changes in geographical ranges and incidence of vector borne disease
Changed local ecology of water borne and food borne infective agents	Changed incidence of diarrhoeal and other infectious diseases
Changed food productivity (especially crops) through changes in climate and associated pests and diseases	Malnutrition and hunger, and consequent impairment of child growth and development
Sea level rise with population displacement and damage to infrastructure	Increased risk of infectious disease, psychological disorders
Biological impact of air pollution changes (including pollens and spores)	Asthma and allergies; other acute and chronic respiratory disorders and deaths
Social, economic, and demographic dislocation through effects on economy, infrastructure, and resource supply	Wide range of public health consequences: mental health and nutritional impairment, infectious diseases, civil strife

Factors determining the vulnerability of populations[8]

- Poverty and the associated lack of resources and technical infrastructure
- Nutritional status (for example, those people of sub-Saharan Africa who lack food security[9])
- Isolation
- Physical location (for example, populations of the coast or small islands, who are exposed to rising seas and salt water intrusion into soil and fresh water)
- Cultural inflexibility
- Political rigidity

Variations in vulnerability would be compounded by regional differences in climate change. The modelling of climate change on a regional basis is improving. Increases in temperature would generally be greater at higher latitude, and changes in precipitation would vary in such a way that droughts would occur in some regions that are already semiarid while rainfall would increase in others.[1]

Potential health effects of climatic change

The various potential health effects of climatic change—direct and indirect, immediate and delayed—are summarised in table 1.[7 10] Some would be beneficial. For example, warmer temperatures would mean milder winters in cool-temperate countries, which should reduce the mortality peak among older people in winter.[11] An increase in summer temperatures in currently hot zones might reduce the viability of mosquito populations. Most of the anticipated effects, however, would be adverse. Shifts in climate means and variability would perturb important physical and biological systems to which human health is biologically and culturally adjusted.

Direct effects of climate change

The direct health effects would include changes in mortality and morbidity from heatwaves and thermal stress.[12-14] Climatologists forecast an increase in the frequency of heatwaves (because of both the rising mean temperature and a possible increase in weather variability). Relatively little is known, however, about the capacity of human populations to adapt physiologically and culturally to such changes over decades. Also, since extremes of heat and cold affect elderly and sick people in particular, the average impact on life expectancy may not be large.[10 13]

Other direct effects would include those on respiratory health of altered concentrations of aeroallergens (such as spores and moulds),[15] of air pollutants such as ozone produced by photochemical reactions that are sensitive to temperature, and the many different health consequences of an altered tempo of extreme weather events, including storms and floods.[7]

Indirect effects

Indirect health effects, many of which would result from the perturbation of complex ecological systems, are of potentially greater consequence. These include changes in the range and activity of infectious diseases borne by vector organisms; altered transmission of infections from person to person (including food poisoning and transmission of pathogens carried by water); the nutritional and health consequences of regional changes in agricultural productivity; and the various consequences of rising sea levels.[7 10] Public health would also be affected by population movements and by regional conflicts over food and water in shortages caused by climatic changes.[16 17]

Infectious diseases

Changes in the risks of infectious disease would occur particularly as a result of climatic influences on the vector organisms for diseases such as malaria, dengue fever, trypanosomiasis, the viral encephalitides (including those in temperate zones), and schistosomiasis.[10 18 19] Increased temperatures and changed rainfall would affect the range, proliferation, and behaviour of vector organisms and intermediate hosts and the viability and maturation rates of the infectious agents. While richer, developed countries might be able to maintain public health defences against an extension (or reintroduction) of vector borne infections, populations on the margins of endemic areas in tropical and subtropical countries would be at increased risk.

Recent empirical (analogue) studies in Zimbabwe, Rwanda, and Ethiopia, which have used natural climate variability to foreshadow aspects of future climate change, indicate that such change would cause malaria to move to higher altitudes and thereby affect highland populations who are currently protected.[18 20 21] Other recent analogue studies have confirmed the sensitivity of both malaria and dengue fever to climatic variations between years.[22 23 24] Interestingly, there have been reports of a recent upward movement of malaria, dengue fever, or their mosquito vectors in several continents in conjunction with retreating glaciers and ascent of alpine plants.[25]

Simulation of scenarios of standard climatic change using integrated mathematical modelling shows that the potential geographical range for transmitting malaria would expand.[26-29] Approximately 45% of the world's population currently live in zones that are defined climatically as areas of potential malaria transmission, and assuming that other factors remain constant this would increase to around 60% towards the end of the next century.[10 26 27] Figure 2 shows the potential future transmissibility of malaria under likely conditions of climate change as modelled by the widely used ECHAM-1 general circulation model.[26] Similar mathematically modelled projections exist for dengue fever and schistosomiasis.[30]

The highly aggregated models used to make global forecasts necessarily gloss over many regional differences. With sufficient localised information it is possible to scale down and retune the mathematical model to match local conditions. The application of such a model to forecast the changes in potential malaria transmission in Zimbabwe is shown in figure 3.

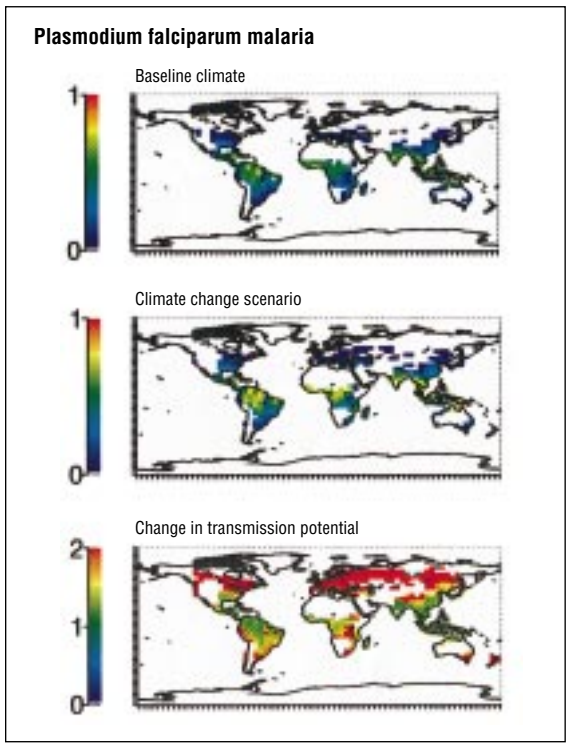

Fig 2 Estimated changes in the potential transmission of malaria as a result of climate change brought about by doubling the atmospheric carbon dioxide concentration (from Martens[27]). Top map shows current distribution of climatic zones, colour coded accorded to the estimated capacity to transmit malaria; middle map shows estimated distribution of equivalent potential transmission zones under climate change later next century; lower map shows difference between these two—that is, the estimated change in potential transmissibility of malaria. Transmission potential is scaled arithmetically from zero to 1 (maximum) in the upper and middle maps and as a multiplication factor (2=doubling) in the lower map

Climate change in temperate regions would also affect some infectious diseases carried by vector organisms[10]:

- Viral encephalitis borne by ticks: occurs in parts of western Europe and Scandinavia and is sensitive to the climate
- Leishmaniasis: currently endemic in the rural Mediterranean region of Europe and in the eastern Mediterranean. Climate change may extend the habitat of the sandfly vector northwards
- Lyme disease: caused by the spirochaete *Borrelia burgdorferi*, transmitted in Europe and the north-eastern United States by the tick *Ixodes ricinus*. Temperature influences the tick's life cycle of three stages (larvae, nymphs, adults) and, hence, the probability of transmission of the spirochaete
- Malaria: endemic malaria was widely present in Europe earlier this century.[31] It is appropriate to consider how bioenvironmental stresses induced by climate might eventually breach existing protective public health measures.

Climatic change would also influence various infections which are directly transmitted, especially those caused by contamination of drinking water and food.[32] Recent evidence suggests that the spread of cholera is aided by warmer coastal and estuarine waters and their associated algal blooms, since phytoplanktonic and zooplanktonic organisms act as a natural reservoir for *Vibrio cholerae*.[7 17 33]

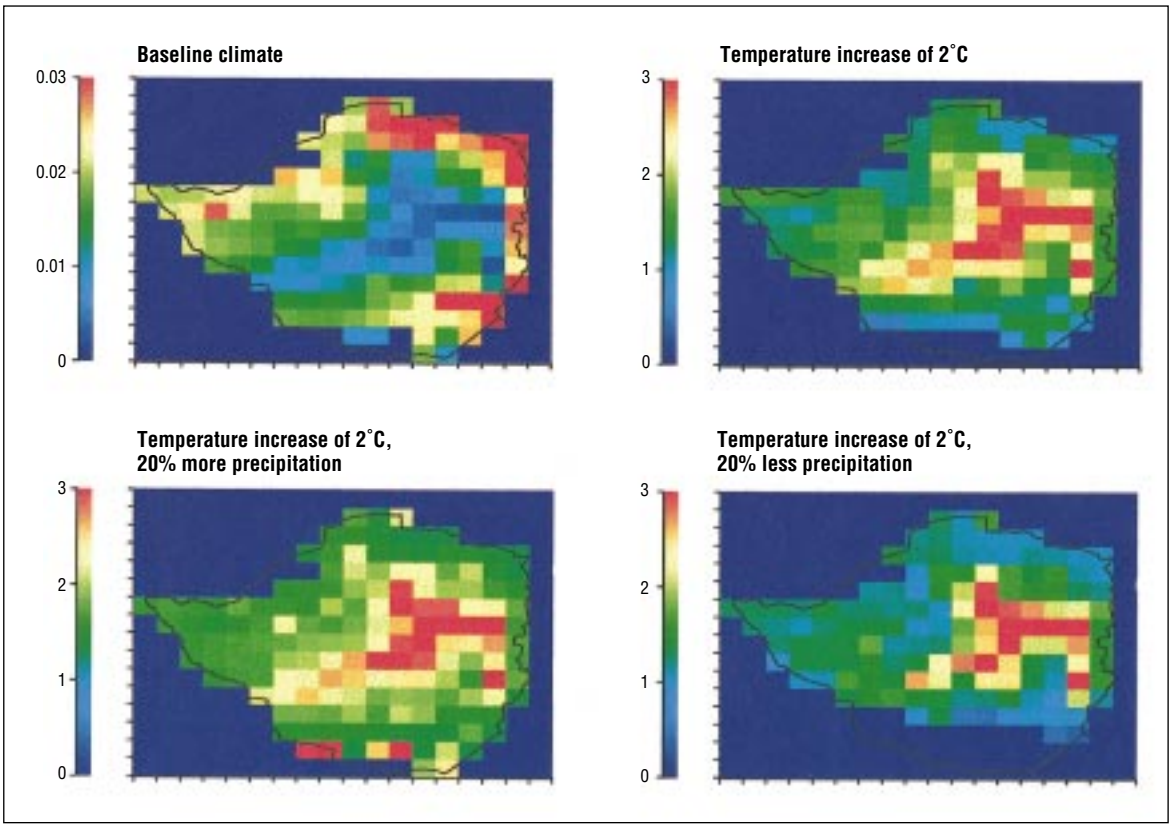

Fig 3 Changes in the potential transmission of *Plasmodium falciparum* malaria in Zimbabwe modelled under three scenarios of climate change (from Martens[27]). Note that the highland region runs centrally from the north east to the south west. For the baseline climate, malaria prevalence is shown on a percentage scale; for the three other maps the change in transmission potential is shown as a multiplier of that baseline prevalence

Food production, hunger, and malnutrition

Climate change would affect the production of food, especially that of cereal crops. Regional gains and losses would reflect the local balance of changes in temperature, soil moisture, carbon dioxide "fertilisation," and pest and pathogen activity. Studies using mathematical modelling consistently show that tropical and subtropical countries would be most affected. Furthermore, many communities that rely on traditional agriculture may lack the resources and adaptability to switch to alternative crops and production methods. Although there would be some mid-continental drying in summer months in North America and Europe,[7 34 35] agricultural production in high latitude, temperate zones (for example, Canada and much of Siberia) might increase. Long term climatic changes, however, might have a net negative impact on world agriculture.[10 34]

Poor and economically underdeveloped populations who would be unable to offset reduced agricultural yields by trade would be adversely affected. Hunger and malnutrition increase the risk of infant and child mortality and cause physical and intellectual stunting. Energy levels, work capacity, and health status are reduced in adults. One widely quoted study has forecast the additional number of hungry people attributable to climate change by the year 2060, allowing for plausible future trajectories of demographic, economic, and trade liberalisation processes.[34] The estimate varied between an additional 40 million and 300 million relative to a future background total of around 600 million hungry people.

Water supplies, essential for agriculture, animal husbandry, and personal hygiene, may also be adversely affected by climatic change in many regions. Tensions over shortages of fresh water, especially in low to middle latitude locations where adjoining countries share river basins,[16] would be exacerbated by changes in rainfall related to the climate.[7 10]

Recent developments, 1996-7

- The Intergovernmental Panel on Climate Change has included a full chapter on potential health impacts in its second assessment report.[1] The first report, in 1990, gave scant attention to health
- The World Health Organisation, United Nations Environment Programme, and World Meteorological Organisation have published *Climate Change and Human Health*, a comprehensive volume which considers the implications for science and policy[7]
- In Britain, the Climate Change Impacts Review Group of the Department of Environment has published a report with a major section on potential health consequences for the British population.[38] The Global Environmental Research Office has published a report advocating interdisciplinary, jointly funded, research initiatives.[39] The Medical Research Council and Department of Health were represented in that process
- Various national governments and research agencies have funded research into climate change and human health. These include the United States, Canada, the Netherlands, and Australia—but there has been no equivalent initiative in Britain

Sea level rise: effects on coastal regions and populations

The Intergovernmental Panel on Climate Change has forecast that sea level will rise approximately 40 cm by 2100—a rate of increase several times faster than that over the past century. The importance of this forecast lies in the fact that over half the world's population lives within 60 km of the sea. An increase would affect various processes and structures on which food production, economies, and public health depend. The displacement of communities living on the coast or on small islands would be a particular health hazard, especially in poorer, populous countries with few material resources.[7 9 36] At today's population level an increase of half a metre would approximately double the number of people who experience flooding annually—currently around 46 million.[37] The disposal of sewage and waste water, the physical safety of coastal structures, the viability of coral reefs and wetlands (fish nurseries), and the ecology of some infectious diseases (for example, malaria and cholera) would also be affected.[7 10] A rise in sea level, ocean warming, and changes in currents and nutrient flows would all contribute to alterations in marine ecosystems.[10] In relation to health, the consequences include algal blooms (implicated in cholera transmission) and the production of toxins in edible fish and shellfish.[10]

International and national developments

Recognition that climate change may adversely affect human health has prompted a rapid expansion of research and evaluation into the topic. The box shows noteworthy developments during 1996-7.

Research needs and ethical considerations

The main research strategies for estimating the health effects of future climate change (analogue studies, integrated mathematical modelling, the use of expert judgment in relation to diffuse or complex consequences, and experimental studies of specific components of the climate change process), the role of monitoring, and the implications for the formulation of social policy are the focus of the accompanying paper.[6] It is important to note here, however, that it is misleading to view future and present environmental health problems as competing for attention in research and policymaking. The economic structures, social inequities, industrial practices, and consumer behaviour that underlie many of today's public health problems also underlie the growing pressures on the world's natural, life supporting systems. The advent of global environmental health hazards further underlines the continuing vulnerability of poorer, economically underdeveloped populations. We should therefore be seeking far reaching solutions through social policy—solutions that reduce both today's public health problems and the likelihood of future damage to the global biophysical systems that support life.

We received assistance and helpful comments from Sari Kovats.

1 Intergovernmental Panel on Climate Change (WGI). JT Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K, eds. *Climate change, 1995—the science of climate change: contribution of Working Group I to the second assessment report of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press, 1996.
2 Wigley TML. A successful prediction? *Nature* 1995;376:463-4.
3 Kerr RA. Studies say—tentatively—that greenhouse warming is here. *Science* 1996;268:1567-8.
4 McMichael AJ. *Planetary overload. Global environmental change and the health of the human species*. Cambridge: Cambridge University Press, 1995.
5 McMichael AJ, Martens WJM. The health impacts of global climate change: grappling with scenarios, predictive models and multiple uncertainties. *Ecosystem Health and Medicine* 1995;1:15-25.
6 Haines A, McMichael AJ. Climate change and health: implications for research, monitoring, and policy. *BMJ* (in press).
7 McMichael AJ, Haines A, Slooff R, Kovats S, eds. *Climate change and human health*. Geneva: World Health Organisation, 1996. (WHO/EHG/96.7.)
8 Woodward AJ, Hales S, Weinstein P.. Climate change and human health in the Asia-Pacific region: who will be most vulnerable? *Climate Research* (in press).
9 Banea M, Tylleskar T, Rosling H. Konzo and Ebola in Bandunu region of Zaire. *Lancet* 1997;349:621.
10 McMichael AJ, Ando M, Carcavallo R, Epstein P, Haines A, Jendritzky G, et al. Human population health. In: Watson RT, Zinyowera MC, Moss RH, eds. *Climate change 1995—impacts, adaptations, and mitigation of climate change*. New York: Cambridge University Press, 1996:559-84.
11 Langford IH, Bentham G. The potential effects of climate change on winter mortality in England and Wales. *Int J Biometeorol* 1995;38:141-7.
12 Kilbourne E. Illness due to thermal extremes. In: Last JM, Wallace RB, eds. *Public health and preventive medicine*. 13th ed. Norwalk, CT: Appleton Lange, 1992; 491-501.
13 Kalkstein L. Direct impacts in cities. *Lancet* 1993;342:1397-9.
14 Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, et al. Heat-related deaths during the July 1995 heat wave in Chicago. *N Engl J Med* 1996;335:84-90.
15 Emberlin J. The effects of patterns in climate and pollen abundance on allergy. *Allergy* 1994;49:15-20.
16 Postel S. *The last oasis: facing water scarcity*. London: Earthscan Publications, 1992.
17 Myers N, Kent J. *Environmental exodus: an emergent crisis in the global arena*. New York: Climate Institute, 1995.
18 Patz JA, Epstein PR, Burke TA, Balbus JM. Global climate change and emerging infectious diseases. *JAMA* 1996;275:217-23.
19 Rogers DJ, Packer MJ. Vector-borne diseases, models and global change. *Lancet* 1993;342:1282-84.
20 Loevinsohn M. Climatic warming and increased malaria incidence in Rwanda. *Lancet* 1994;343:714-18.
21 Tulu AN. *Determinants of malaria transmission in the highlands of Ethiopia: The impact of global warming on morbidity and mortality ascribed to malaria*. London: London School of Hygiene and Tropical Medicine, 1996. (PhD thesis.)
22 Epstein P. Emerging infectious diseases and global change: where are we headed? In: DeCock K, Greenwood B, eds. *New and resurgent infections*. Chichester: Wiley (in press).
23 Bouma MJ, van der Kaay HJ. The El Niño southern oscillation and the historic malaria epidemics on the Indian subcontinent and Sri Lanka: an early warning system for future epidemics? *Tropical Medicine and International Health* 1996;1:86-96.
24 Hales S, Weinstein P, Woodward A. Dengue fever epidemics in the South Pacific: driven by El Niño southern oscillation? *Lancet* 1996;348:1664-5.
25 Burgos JJ, Curto de Casas SI, Carcavallo RU, Galindez GI. Global climate change in the distribution of some pathogenic complexes. *Entomologia y Vectores* 1994;1:69-82.
26 Martens WJM, Niessen LW, Rotmans J, et al. Potential impact of global climate change on malaria risk. *Environmental Health Perspectives* 1995;103:458-64.
27 Martens WJM. *Health impacts of climate change and ozone depletion. An eco-epidemiological modelling approach*. Maastricht: University of Maastricht, 1997.
28 Martin P, Lefebvre M. Malaria and climate: Sensitivity of malaria potential transmission to climate. *Ambio* 1995;24:200-7.
29 Sutherst RW. Arthropods as disease vectors in a changing environment. In: Lake JV, Bock GR, Ackrill K eds. *Environmental change and human health*. New York: Wiley, 1983:124-45. (Ciba Foundation symposium.)
30 Martens WJM, Jetten TH, Focks DA. Sensitivity of malaria, schistosomiasis and dengue to global warming. *Climatic Change* 1997;35:145-56.
31 De Zulueta J, Ramsdale CD, Coluzzi M. Receptivity to malaria in Europe. *Bull WHO* 1975;52:109-11.
32 Bentham GC, Langford IH. Climate change and the incidence of food poisoning in England and Wales. *Int J Biometeorol* 1995;39:81-6.
33 Colwell R. Global climate and infectious disease: the cholera paradigm. *Science* 1996;274:2025-31.
34 Parry ML, Rosenzweig C. Food supply and the risk of hunger. *Lancet* 1993;342:1345-7.
35 Reilly J, Baethgen W, Chege FE, van de Geijn SC, Erda L, Iglesias A, et al. Agriculture in a changing climate: impacts and adaptation. In: Watson RT, Zinyowera MC, Moss RH, eds. *Climate change 1995—impacts, adaptations, and mitigation of climate change*. New York: Cambridge University Press, 1996:427-67.
36 Nicholls RJ, Leatherman SP. The implications of accelerated sea-level rise for developing countries: a discussion. *Journal of Coastal Research* 1995;14:303-23.
37 Baarse G. *Development of an operational tool for global vulnerability assessment (GVA): update of the number of people at risk due to sea-level rise and increased flooding probabilities*. The Hague: Ministry of Transport, Public Works and Water Management, 1995. (CZM Centre publication No 3.)
38 Climate Change Impacts Review Group. *The potential effects of climate change in the United Kingdom. Second report*. HMSO: London, 1996. (Report to UK Department of Environment.)
39 Report of Expert Panel, Inter-Agency Committee on Global Environmental Change. *UK national strategy for global environmental research*. Swindon: UK Global Environment Research Office, 1996.

(Accepted 13 June 1997)